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Experimental Investigation of the Effect of Temperature on Friction Pressure Loss of Polymeric Drilling Fluid Through Vertical Concentric Annulus

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ABSTRACT

Accurate estimation of annular friction pressure loss is necessary to perform drilling and well completion operations without lost circulation, pipe sticking or more serious well control problems. Determination of friction pressure loss for Newtonian and non-Newtonian fluids has been investigated in several experimental and theoretical works by considering the effects of eccentricity, pipe rotation or pipe geometry. However, there is a gap in the studies about the temperature effect that is important especially in geothermal wells.

This study experimentally investigated the effect of temperature on friction pressure loss through vertical concentric annulus by using water and the polymer based drilling fluid including Polyanionic Cellulose and Xanthan Gum. Experiments were conducted in flow loop having 21-ft smooth and concentric annular test section (2.91 in ID casing x 1.85 in OD pipe).

The effect of temperature on rheological model parameters, apparent viscosity, Reynolds number was examined. It was found that consistency index and yield point were more sensitive to change in temperature than flow behavior index. Also, apparent viscosity decreased exponentially with increasing temperature and this decrease was more obvious in low shear rate values. Then, according to Reynolds number – temperature plot, earlier regime transition was observed with increasing temperature.

As a result, increasing temperature caused the decrease in friction pressure loss, and temperature effect should be considered in future experimental and theoretical studies in order to estimate friction pressure loss in annuli precisely.

1. INTRODUCTION

For drilling and well completion operations, friction pressure loss should be estimated precisely to prevent lost circulation, pipe sticking, kicks or other serious problems. These problems can lead to interrupt operations and even abandon the well. In order to simulate real drilling conditions, several factors such as eccentricity, inner pipe rotation, annular geometry or flow regime have been examined theoretically and experimentally by now.

In literature, Metzner and Reed (1955) investigated pipe flow firstly for non-Newtonian fluids by finding a relationship between friction pressure loss and generalized Reynolds number for laminar and turbulent flow regimes. Then, Dodge and Metzner (1959) studied turbulent pipe flow conditions with Power Law Model, and they proposed a correlation between friction factor and generalized Reynolds number. To extend the studies from pipe to annular flow, equivalent diameter definitions were presented. Mostly known definitions are hydraulic diameter, slot flow approximation (Bourgoyne Jr. et al., 1991), Lamb's diameter (Lamb, 1945) and Crittendon's diameter (Crittendon, 1959). Jensen and Sharma (1987) studied about finding the best combination of friction factor and equivalent diameter definitions in order to calculate friction pressure loss by applying Bingham Plastic and Power Law model. They found a correlation for friction factor and combined with hydraulic diameter and then, this gave the best result for these rheological models.

Herschel-Bulkley model was used to predict friction pressure loss through the annulus following Reed and Pilehvari (1993) method where a model in order to estimate annular friction pressure loss by finding a relationship between Newtonian Pipe flow and non-Newtonian annular flow is presented. An "effective diameter" term for laminar flow that includes combined geometry shear-rate correction factor (G) is introduced. Subramanian and Azar (2000) examined the flow of different non-Newtonian fluids including polymer-based drilling fluid through pipe and annulus. Results showed that Herschel-Bulkley model gave the best fit for concentric annulus in laminar flow regime. For turbulent flow, polymer drilling fluid acted as drag reducing fluid and thus the term of pipe roughness in friction pressure loss prediction caused larger results than experiments. Zamora et al. (2005), Demirdal and Cunha (2007) and Dosunmu and Shah (2015) also investigated the effects of different flow regimes, rheological models and equivalent diameter concepts. Studies about the effects of inner pipe rotation and eccentricity in addition to these parameters were conducted by Ozbayoglu and Sorgun (2010), Anifowoshe and Osisanya (2012) and Rooki (2015).

Temperature effect has only been considered by Ulker et al. (2017) in estimation of friction pressure loss through annulus. They found an empirical correlation for friction pressure loss by considering Reynolds number, Taylor number and Prandtl number. Literature survey showed that although annular friction pressure loss has been examined theoretically and experimentally with the effects of types of fluids, eccentricity of pipe, pipe rotation, pipe roughness, different equivalent diameter definitions, friction factor correlations and flow patterns, for non-Newtonian fluids, temperature effects have not been investigated yet. The main aim of this paper is to experimentally investigate the effect of temperature on friction pressure loss through vertical concentric annulus.

2. EXPERIMENTS

2.1 Experimental Setup

Experiments were conducted at flow loop laboratory of Middle East Technical University Department of Petroleum and Natural Gas Engineering. The schematic of flow loop is demonstrated in Figure 1.

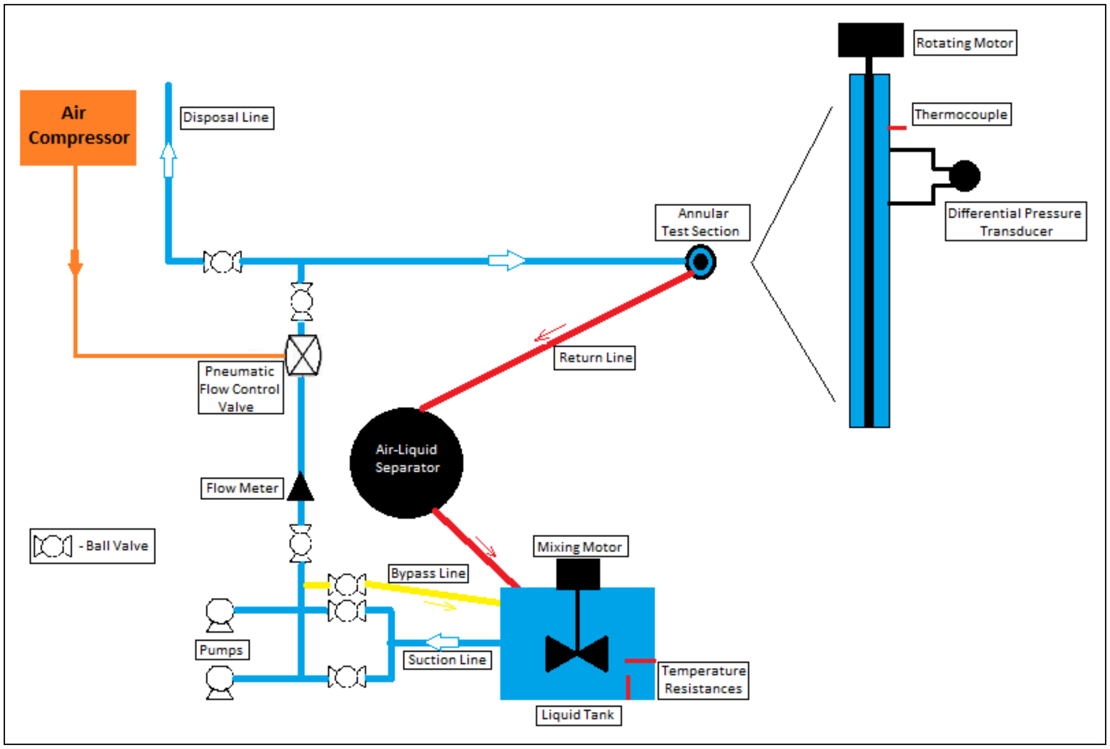

Figure 1: Schematic of Flow Loop

Flow loop mainly includes liquid tank with mixer and temperature resistances, centrifugal pumps, valves to control flow, flow meter and annular test section having differential pressure transducer and thermocouple.

Friction pressure loss measurements were performed at annular test section. The length of test section is 21 ft and it has 2.91" ID transparent plexiglas pipe representing casing and 1.85" OD drill pipe. Also, dial readings at different shear rates are measured with viscometer having the capacity of six readings.

2.2 Drilling Fluid Preparation

Experiments were conducted with water and polymeric drilling fluid. Drilling fluid was prepared by using polyanionic cellulose (REOPAC HV) (0.50 lb/bbl), xanthan gum (REOZAN D) (0.75 lb/bbl) and triazine based biocide (GEOCIDE T) (1 lt/1000 lt) provided by GEOS Energy Inc. REOPAC HV is used as viscosifier and fluid loss control additive, REOZAN D is used as viscosifier, and GEOCIDE T is added to the liquid tank to control bacteria growth. These are mostly used in geothermal drilling applications.

2.3 Experimental Procedure

Water experiments were performed at 20°C, 25°C, 35°C and 45°C with flow rates changing between 40 gpm and 110 gpm. Data were taken from annular test section when the system was steady. Polymeric drilling fluid experiments were conducted at 24°C, 30°C, 37°C and 44°C with the flow rates between 25 gpm and 110 gpm. Like water experiments, before taking friction pressure loss data, the system was observed to see if steady state has been obtained. Rheological measurements were conducted at steady state for each temperature.

3. RESULTS AND DISCUSSION

3.1 Water Experiments

Experiments with water were conducted to see the effect of temperature on the flow of Newtonian fluids in vertical concentric annulus. Calculations for friction pressure loss through annulus were performed by applying Newtonian model with using slot flow approximation to represent annular geometry. (Bourgoyne Jr. et al., 1991)

In order to investigate the effect of temperature, measured friction pressure loss vs. Reynolds number graph was plotted (Figure 2).

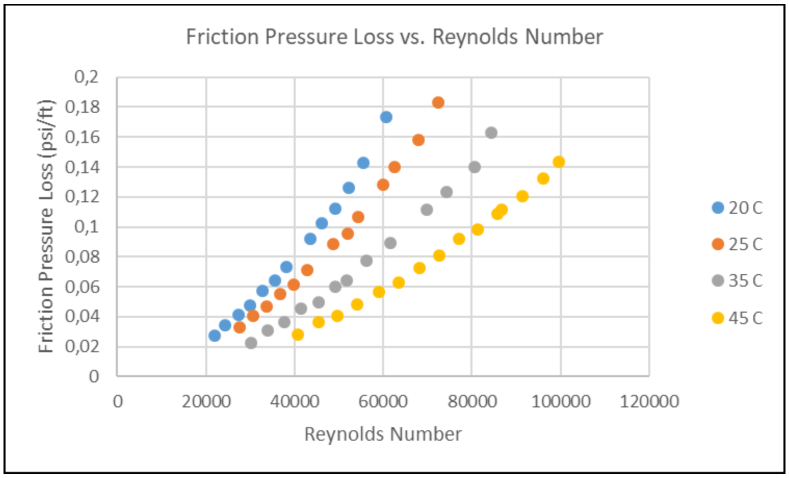

Figure 2: Friction Pressure Loss vs. Reynolds Number for Water

As shown in the graph, increasing Reynolds number leads to change in friction pressure loss more pronouncedly due to viscosity and density terms in Reynolds number. Change in viscosity is larger than density. This causes increase in Reynolds number and then, friction pressure loss. In addition, friction pressure loss increased with Reynolds number for all temperatures but this increase was more pronounced at lower temperature

3.2 Drilling Fluid Experiment

Friction pressure loss estimation was performed by applying the method of American Petroleum Institute Recommended Practice 13D for Rheology and Hydraulics of Oil-Well Drilling Fluids. (American Petroleum Institute (API), 2009). This manual uses Herschel-Bulkley rheological model to predict friction pressure loss. Therefore, firstly, the three parameters of Herschel-Bulkley model was found by using SOLVER function of Microsoft Excel instead of field measurements explained in API RP 13D manual due to inadequacy of viscometer. Table 1 demonstrates the parameters to calculate friction pressure loss.

Table 1: Friction Pressure Loss Calculation Parameters

Temperature (˚C)	24	30	37	44
Density (ppg)	8.323	8.309	8.29	8.267
Yield Point (τ_y) (lb/100 ft^2)	2.18	1.44	1.18	1.14
Flow Behavior Index (n)	0.52	0.48	0.45	0.47
Consistency Index (K) (lb-sec^n/100 ft^2)	0.74	0.89	0.92	0.69
Power Law Flow Behavior Index (n_p)	0.38	0.38	0.37	0.38

After determining the model parameters, friction pressure losses were estimated. According to API RP 13D, hydraulic radius (HR) was used to represent annular geometry but, when flow regime changed from laminar to turbulent, experimental results did not match with theoretical results and started to be closer to friction pressure loss estimated by using slot flow approximation (SA) as shown in Figure 3. The reason of this deviation was found as the regime transition by determining the lower and upper critical Reynolds number values for all temperatures. In Figure 4 and 5, friction pressure loss was calculated by using hydraulic radius in laminar flow regime and slot flow approximation after the end of laminar flow regime at 24 and 30°C. All temperature values gave the best fit with this combination of equivalent diameter concepts.

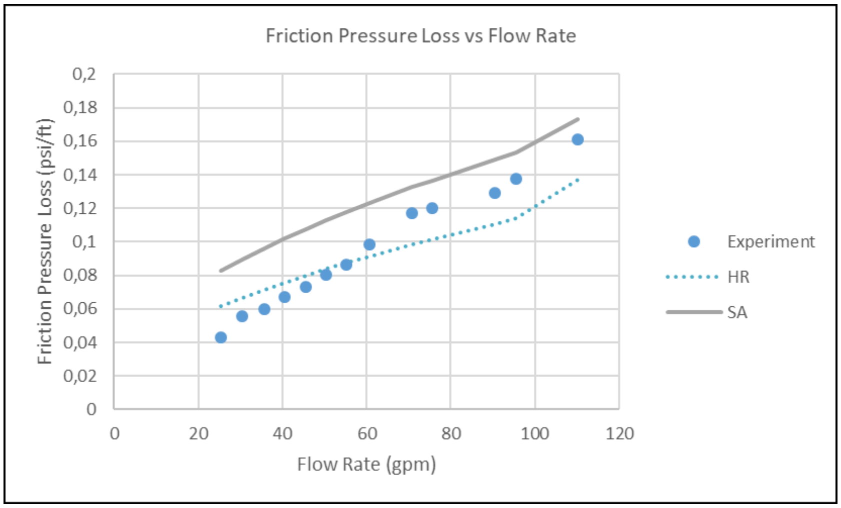

Figure 3: Friction Pressure Loss vs. Flow Rate at 24°C

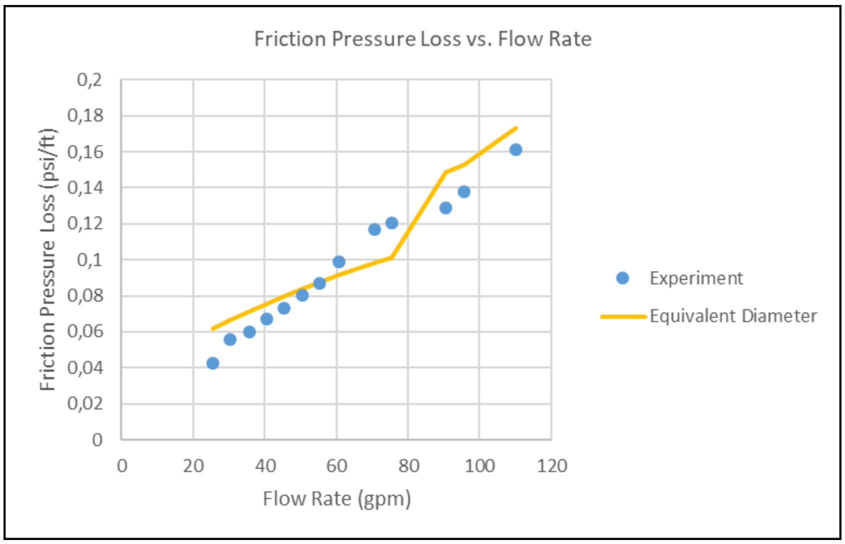

Figure 4: New Friction Pressure Loss vs. Flow Rate at 24°C

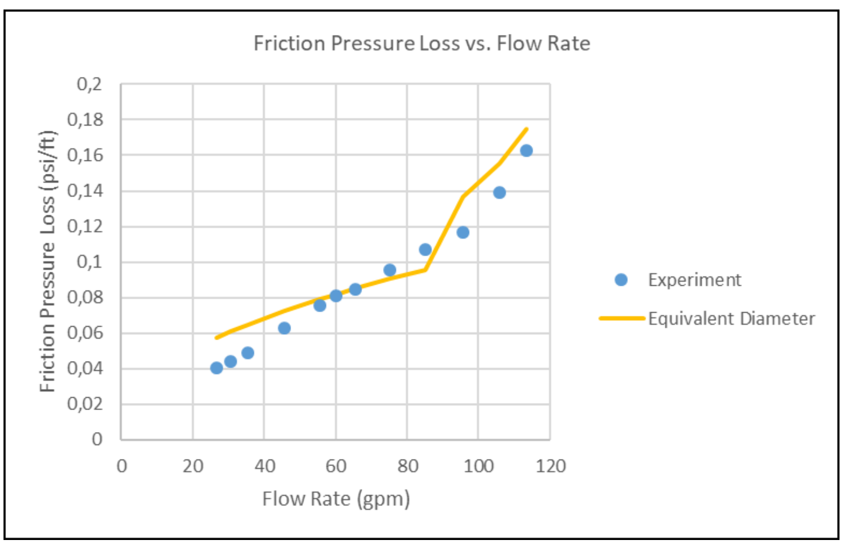

Figure 5: New Friction Pressure Loss vs. Flow Rate at 30°C

In order to investigate the effect of temperature, firstly, Herschel-Bulkley parameters were examined. Below graphs show the effect of temperature on Herschel-Bulkley model parameters.

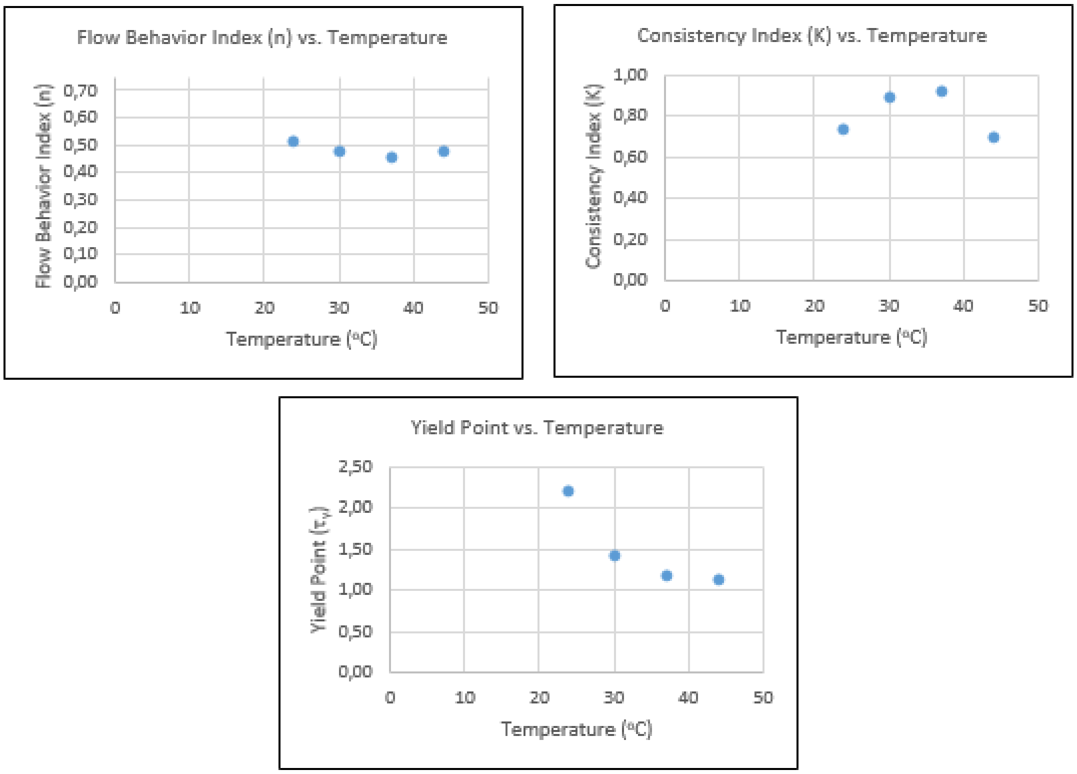

Figure 6: Herschel-Bulkley Model Parameters vs. Temperature

It was observed that flow behavior index was not affected by change in temperature. However, consistency index initially increased and then decreased. Normally, increasing temperature changes consistency index reversely since it represents the viscosity of the fluid at low shear rates (MI Swaco, 1998). Thus, the effect of temperature on flow behavior index and consistency index could not be properly understood. Then, yield point decreased with increasing temperature as expected.

In order to see the combined behavior of these parameters, apparent viscosity values were examined. In calculation of apparent viscosity, like friction pressure loss estimation, hydraulic radius in laminar flow regime and slot flow approximation after the laminar flow regime were used. For different flow rates, apparent viscosity vs. temperature graph is shown in Figure 7.

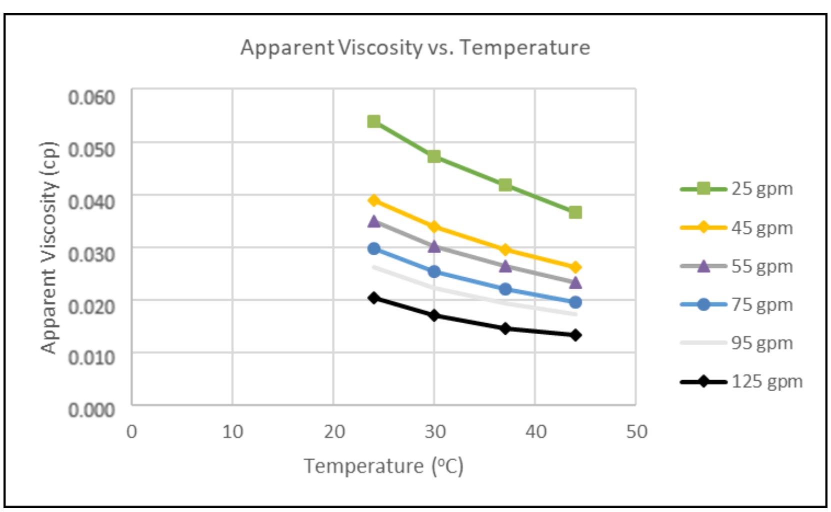

Figure 7: Apparent Viscosity vs. Temperature

Apparent viscosity changed with temperature inversely as expected and higher viscosity values were influenced by temperature much more than lower ones. Also, decrease in apparent viscosity had also inverse relationship with increasing flow rate due to shear thinning behavior of polymer-based fluids.

Generalized Reynolds number was also investigated. Like apparent viscosity, this number was calculated by using same equivalent diameter definitions. Figure 8 shows the graph of generalized Reynolds number vs. temperature with different flow rates.

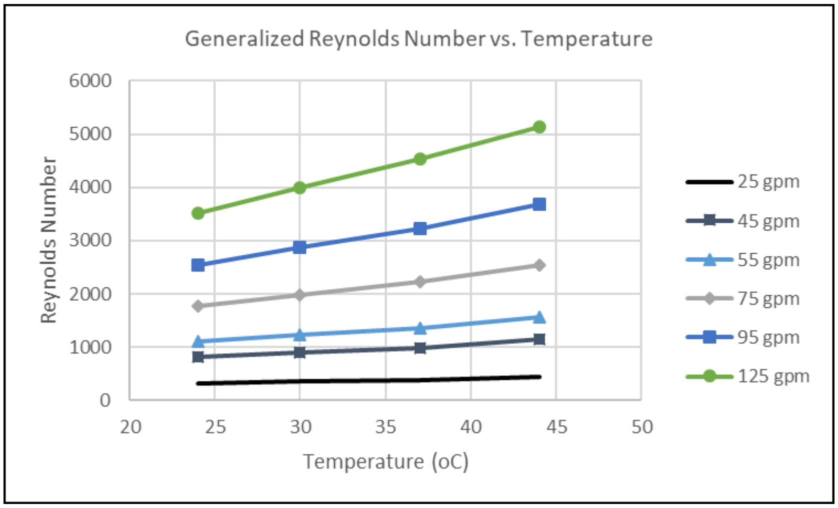

Figure 8: Generalized Reynolds Number vs. Temperature

For higher flow rates, increase in Reynolds number became more distinct. Since, apparent viscosity and density that are temperature dependent variables affect Reynolds number, in other words, since the decrease in viscosity is larger than density, Reynolds number starts to increase. Therefore, regime transition became earlier with the effect of temperature. Also, measured friction pressure loss vs. Reynolds number plot shows the decrease in friction pressure loss with increasing temperature. This plot shown in Figure 9.

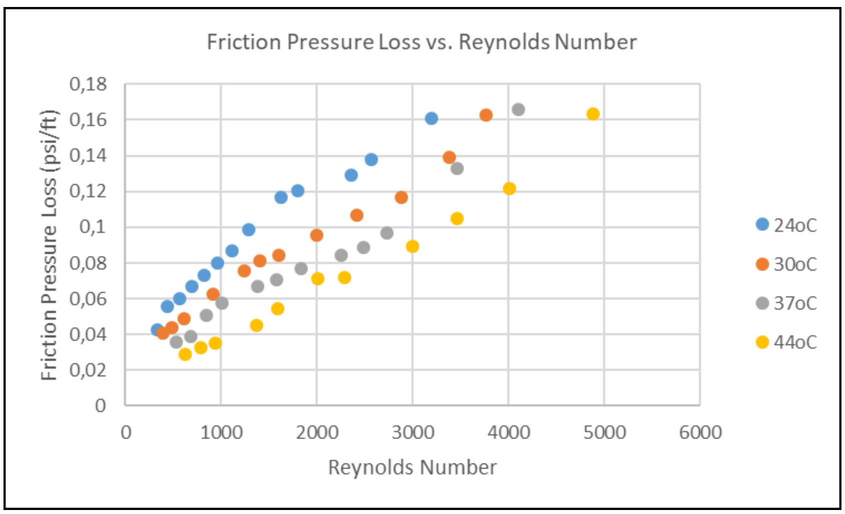

Figure 9: Friction Pressure Loss vs. Reynolds Number for Polymeric Drilling Fluid

4. CONCLUSIONS

1. Friction pressure loss vs. flow rate plot for water gave good agreement with theoretical results calculated by using Newtonian model with slot flow approximation. In addition, Reynolds number change became more distinct at lower temperature.

2. Consistency index and yield point parameters of polymeric drilling fluid are more sensitive to change in temperature than flow behavior index. Also, only yield point showed the expected behavior with increase in temperature.

3. Apparent viscosity that gave the combined behavior of rheological parameters showed exponential decrease with increasing temperature especially in lower shear rates. The reason of this behavior was the effect of temperature and shear-thinning behavior of polymeric fluids.

4. Transition of laminar to turbulent flow became earlier with increasing temperature due to change more pronounced change in Reynolds number at higher shear rates.

5. Friction pressure loss decreased with increasing temperature when examining measured friction loss vs. Reynolds number plot.

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